

Original article

Sleep quality improved following a single session of moderate-intensity aerobic exercise in older women: Results from a pilot study

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Abstract

Background: Poor sleep quality is associated with adverse effects on health outcomes. It is not clear whether exercise can improve sleep quality and whether intensity of exercise affects any of the effects.

Methods: Fifteen healthy, non-obese (body mass index = 24.4 ± 2.1 kg/m², mean \pm SD), sedentary (<20 min of exercise on no more than 3 times/week) older women (66.1 ± 3.9 years) volunteered for the study. Peak oxygen consumption (VO_{2peak}) was evaluated using a graded exercise test on a treadmill with a metabolic cart. Following a 7-day baseline period, each participant completed two exercise sessions (separated by 1 week) with equal caloric expenditure, but at different intensities (60% and 45% VO_{2peak}, sequence randomized) between 9:00 and 11:00 am. A wrist ActiGraph monitor was used to assess sleep at baseline and two nights following each exercise session.

Results: The average duration of the exercise was 54 and 72 min, respectively at 60% (moderate-intensity) and 45% VO_{2peak} (light-intensity). Wake time after sleep onset was significantly shorter ($p = 0.016$), the number of awakenings was less ($p = 0.046$), and total activity counts were lower ($p = 0.05$) after the moderate-intensity exercise compared to baseline no-exercise condition.

Conclusion: Our data showed that a single moderate-intensity aerobic exercise session improved sleep quality in older women.

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Keywords: Actigraphy; Activity counts; Exercise; Older adults; Sleep quality; Wake after sleep onset

1. Introduction

Poor sleep quality is associated with adverse effects on health outcomes.^{1,2} A large proportion of older adults tend to have poor, fragmented sleep quality such as waking up frequently.³ The 2003 National Sleep Foundation survey showed that one third of adults aged 64 years and older have at least one sleep-related complaint such as difficulty falling asleep, being awake a lot during the night and waking up too early.⁴

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Exercise is often considered a non-pharmacological approach that could have beneficial effects on sleep. This is supported by epidemiologic studies showing an association between self-reported exercise and better sleep.^{5,6} Additionally, some evidence indicates that aerobically fit individuals have shorter sleep-onset latencies, less wake time after sleep onset, and higher sleep efficiency than their sedentary peers,⁷ and increased fitness has been associated with improvements in subjectively-assessed sleep.⁸ However, results from experimental exercise studies have been mixed. Several studies have shown a positive impact on self-reported sleep among older normal sleepers following exercise training protocols, including 30-min 67%–70% or 30%–40% heart rate reserve of cycling for 3 times/week,⁹ daily 30-min walking, calisthenics, or dancing,¹⁰ and 60-min Tai Chi practice twice a week.¹¹ Positive effects of exercise on sleep have also been

found in studies of seniors who had mild to moderate sleep problems.^{12–16}

Fewer studies of older adults have assessed sleep objectively via polysomnography or actigraphy. Among these studies, beneficial effects of exercise have been shown in older adults following 60%–85% peak heart rate 5 days/week 35–40 min each session,¹⁷ and 60-min moderate-intensity running 3 days/week;^{18,19} however, daily 30 min of mild to moderate physical activity¹⁰ or one afternoon session of 40–42 min of exhaustive aerobic exercise did not influence sleep.⁷ Thus, studies in older adults have presented inconsistent results regarding the effects of exercise on sleep, which may be related to variations in exercise intensity, volume, and time between exercise and sleep,^{20,21} as well as whether sleep was assessed subjectively or objectively.

A few studies in young adults have examined whether the intensity of a bout of exercise alters its effects on sleep: one study found no differences in sleep latency or number of awakenings between exercise bouts at 70% for 30 min and 40% peak oxygen consumption ($\text{VO}_{2\text{peak}}$) with the same exercise dose;²² another study showed that sleep onset latency, wake after sleep onset, rapid eye movement sleep onset, sleep efficiency and slow-wave sleep after treadmill running at 45%, 55%, 65%, and 75% for 40 min were not different from those after no-exercise control.²³ Due to age-related physiological changes,²⁴ exercise may have different effects in older adults from young adults. However, no study has been designed to determine whether the intensity of exercise influences any effect on sleep in older adults. Thus, the purpose of this study was to determine whether light- and moderate-intensity acute exercise sessions that meet public health recommendations for older adults (moderate-intensity activities, accumulate at least 30 or 60 min/day to total 150–300 min/week),^{25,26} improve objectively measured sleep quality in a group of healthy women 61–74 years of age using a crossover design.

2. Methods

2.1. Subjects and screening evaluations

This study was an ancillary to a study designed to examine the effects of exercise intensity on non-exercise activity thermogenesis in older women ([ClinicalTrials.gov](https://clinicaltrials.gov/ct2/show/study/NCT00988299) identifier: NCT00988299). Fifteen healthy, non-obese, older women volunteered for this study (Table 1). This study was approved by the Institutional Review Board of Washington University School of Medicine in St. Louis, MO, USA, and written informed consent was obtained from all subjects before

participation in the study. None of the subjects smoked and all were weight stable (± 1 kg) and sedentary (< 20 min of exercise no more than 3 times/week) for at least 3 months before entering the study.

All subjects completed a comprehensive medical examination, including a detailed self-reported history, physical examination, a resting electrocardiogram, standard blood tests, and an oral glucose tolerance test performed by physicians and nurses in Washington University Clinical Research Unit. Blood tests included: complete metabolic panel, complete blood count, and thyroid stimulating hormone. Standard cut-offs that are used in the hospital and associated clinics for normal values were used to include or exclude subjects. For example, the normal ranges for the following blood variables are: white blood cell count, 4.5–13.5 K/ μL ; red blood cell count, 3.90–5.30 M/ μL ; hemoglobin, 11.5–16.0 g/dL; thyroid stimulating hormone (TSH), 0.46–4.70 $\mu\text{IU/mL}$; blood urea nitrogen (BUN), 5–25 MG/dL; blood creatinine, 0.50–1.00 MG/dL; aspartate transaminase (AST), 8–39 U/L; and alanine aminotransferase (ALT), 9–52 U/L. Subjects with diabetes, impaired fasting glucose, or impaired glucose tolerance based on American Diabetes Association criteria²⁷ were excluded from the study. None of the subjects had evidence of illness, self-reported insomnia, or were taking medications known to affect sleep or to assist sleep. Their daily caffeine intake was less than 500 mg.

2.2. Study protocol

$\text{VO}_{2\text{peak}}$ was evaluated during a graded exercise test on a treadmill. Heart rhythm and rate were continuously monitored (Marquette MAX-1; ParvoMedics, Sandy, UT, USA) and expired air was analyzed by using a metabolic cart (TrueOne 2400; ParvoMedics). Subjects walked at a constant speed and the inclination of the treadmill was increased by 3% every 2 min until volitional exhaustion and/or two of the following criteria were achieved: respiratory exchange ratio ≥ 1.15 ; heart rate greater than the age-predicted maximum ($220 - \text{age (year)}$); or plateau in VO_2 .

Each subject performed two treadmill walking sessions between 9:00 and 11:00 am following an overnight fast. One walking session was at light intensity (45% $\text{VO}_{2\text{peak}}$) and one at moderate intensity (60% $\text{VO}_{2\text{peak}}$) with randomized sequence, separated by at least 1 week. A snack bar (NatureValley, 250 kcal) was provided before the exercise sessions. The two exercise sessions were performed on same day of the week for each individual to reduce the influence of variation in daily schedule on outcomes. No travel across time zone occurred during the 2 weeks prior to the exercise sessions. During the exercise, expired air was analyzed periodically by using a metabolic cart (TrueOne 2400) to ensure the appropriate exercise intensity was achieved. The duration of exercise was variable and ended when subjects have spent 3.5 kcal (14.7 kJ) energy per kg body weight, based on the volume of the oxygen consumed. We chose an equal exercise energy expenditure relative to body weight for all subjects rather than a fixed time period to reduce the influence of body

Table 1
Subject characteristics.

	Mean \pm SD	Range
Age (year)	66.1 \pm 3.9	60.0–74.0
Body weight (kg)	66.9 \pm 8.4	52.5–81.9
Body mass index (kg/m ²)	24.4 \pm 2.1	19.9–28.8
$\text{VO}_{2\text{peak}}$ (mL/kg/min)	22.3 \pm 4.2	14.6–29.7

weight differences on energy expended between subjects. This also allows us to determine the effects of exercise intensity without the influence of differential energy expended during exercise.

Subjects wore a wrist ActiGraph monitor (GT3X+; ActiGraph, Pensacola, FL, USA) 24 h each day for 7 days at baseline, and 48 h after each exercise session. There were no instructions regarding sleep, physical activity, or dietary intake. The output from the monitors was analyzed using the manufacturer provided software ActiLife 6.5. The Cole–Kripke algorithm²⁸ was used to determine minute-by-minute asleep/awake status. Sleep onset was the first minute that the algorithm scored “asleep”. Total sleep time was the total number of minutes scored as “asleep”. Wake after sleep onset was the total number of minutes a subject was awake after sleep onset occurred. Awakening was the number of different awakening episodes as scored by the algorithm. Sleep efficiency referred to the number of minutes asleep divided by the total number of minutes from sleep onset to sleep end (sum of asleep and awakenings after sleep onset).

2.3. Statistical analysis

Data are reported as means \pm SD. Analyses of variance with repeated measures were used to compare sleep parameters at baseline (no exercise) to after light- and moderate-intensity exercise sessions. Paired *t* tests for each pairs of conditions were performed where a significant (or tend-to-be significant) within-subject difference among the three conditions were found. A $p \leq 0.05$ was considered statistically significant, and $0.05 < p < 0.10$ was considered tend-to-be significant.

3. Results

Subjects in this study were non-obese older women (Table 1). The average duration of exercise was 72 ± 15 and 54 ± 11 min, respectively, for the light- (45% $\text{VO}_{2\text{peak}}$) and moderate-intensity (60% $\text{VO}_{2\text{peak}}$) exercise session.

Table 2 displays sleep parameters at baseline without exercise and after light- and moderate-intensity exercise. Total time-in-bed tended to be different among the three conditions ($p = 0.077$). Specifically, it tended to be ~ 30 and 40 min, respectively, less after light- and moderate-intensity exercises ($p = 0.098$ and 0.063, respectively), compared to without

exercise. There were significant differences in wake time after sleep onset among the three conditions ($p = 0.031$). After the moderate-intensity exercise, it was ~ 15 min shorter compared to baseline ($p = 0.016$). There was also a trend for significant differences in the number of awakening episodes ($p = 0.092$), and it was less after the moderate-intensity exercise than at baseline ($p = 0.046$). Likewise, there was a trend for significant differences in total activity counts (p for trend = 0.071), and after the moderate-intensity exercise they were ~ 9400 ($\sim 21\%$) lower than at baseline ($p = 0.05$) (Table 2). There were no differences in sleep time ($p = 0.237$) or average length of awakening episode ($p = 0.362$) among the three conditions.

We also examined these variables in the first and second night after the exercise sessions separately. Results showed similar trends. We thought that the average of the two nights would better represent the exercise effect because sleep can be affected by many factors; therefore, we only presented the average values here.

4. Discussion

The most interesting findings of this study were that after the moderate-intensity aerobic exercise, wake time after sleep onset, number of awakenings, and total activity counts were significantly lower than those parameters when no exercise was performed. After the light-intensity aerobic exercise, the values of these parameters were between those after the moderate-intensity exercise and without exercise, although they were not statistically different from either. This study showed that the moderate-intensity exercise improved sleep quality, and suggested that performing exercise and increasing the intensity of exercise may influence sleep quality positively in older adults.

The reduction in wake time after sleep onset and number of awakenings following exercise may be partly explained by the reductions in the amount of time spent in bed. Nonetheless, the % of time awake after sleep onset was less following light (9%) and moderate exercise (8%) than baseline no-exercise (11%). More importantly, total activity counts were lower (13% and 21% after light- and moderate-intensity exercise, respectively) compared to without exercise. These findings perhaps suggest better sleep quality especially after the moderate-intensity exercise.

A few previous studies have examined whether intensity and duration of exercise influences the effects of single bouts

Table 2
Sleep parameters during 7-day baseline and 48 h after light- and moderate-intensity exercise sessions.

	Baseline	Light-intensity exercise	Moderate-intensity exercise
Total time-in-bed (min)	489 \pm 55	455 \pm 87 ^a	443 \pm 84 ^a
Total sleep time (min)	431 \pm 45	407 \pm 75	402 \pm 82
Wake after sleep onset (min)	54.2 \pm 32.2	43.3 \pm 31.4	36.4 \pm 21.7 ^b
Number of awakening after sleep onset	15.9 \pm 8.4	14.7 \pm 9.5	12.9 \pm 6.2 ^b
Average length of awakening episode (min)	3.8 \pm 1.3	3.4 \pm 1.3	3.3 \pm 1.0
Total activity counts	35,578 \pm 18,855	27,564 \pm 17,420	25,091 \pm 13,433 ^b

^a $0.05 < p < 0.10$, compared to baseline.

^b $p \leq 0.05$, compared to baseline.

of exercise on sleep quality assessed by objective methods in young adults. These studies either did not show exercise impacted sleep compared to no-exercise control,^{23,29} or found no difference among exercise at various intensities or durations on sleep.^{22,29,30} In one study, 30-min running sessions at 45%, 60%, and 75% of $\text{VO}_{2\text{max}}$ did not result in any difference in sleep quality measured by actigraphic monitors.³⁰ In another study, no difference in sleep latency or number of awakenings was found between exercise bouts at 70% $\text{VO}_{2\text{peak}}$ for 30 min and 40% $\text{VO}_{2\text{peak}}$ with the same exercise volume.²² Likewise, sleep latency, wake after sleep onset, rapid eye movement sleep onset, sleep efficiency and slow-wave sleep after treadmill running at 45%, 55%, 65%, and 75% for 40 min were not different from these variables assessed after a no-exercise control treatment.²³ Another study showed that 1 h of cycling exercise at 60% $\text{VO}_{2\text{peak}}$ did not result in any difference in awakening or sleep efficiency, compared to low-intensity exercise and no exercise control condition.²⁹

In the present study, we found significant effects following moderate-intensity exercise compared to without exercise, although light-intensity exercise did not result in statistically different effects. In comparison to the above-mentioned studies, our participants were older; the duration of the moderate-intensity exercise was longer than those exercise bouts at similar intensities;^{23,29,30} and the volume of exercise in our study was greater than at least three^{22,29,30} of the four studies. Thus, both the intensity and volume of exercise may influence its effects on sleep quality. The necessary exercise intensity and volume to make an impact on sleep quality may also be lower in older than in young adults.

In older adults, a study by Edinger et al.⁷ did not find sleep measured by polysomnography was any better after bicycle exercise at incremental 6-min workloads to exhaustive fatigue of 40–42 min. Compared to their study, the moderate-intensity exercise in our study was longer. Most previous studies in older adults examined the effects of a period of exercise training on sleep quality. Although we cannot directly compare our results with these exercise training studies, findings from these studies appear to support that the intensity and volume of exercise influence its effects on sleep quality. For example, in the study by Benloucif et al.,¹⁰ sleep quality was assessed in healthy older adults before and after a 2-week intervention which included a total of 60 min of mild to moderate physical activity. They found that sleep quality did not improve assessed by actigraphy or polysomnography. In contrast, exercise at longer duration and intensity (60 min/day at an intensity equal to the ventilatory threshold) for 24 weeks decreased awake time during sleep in healthy older adults.^{18,19} Additionally, older adults with sleep problems or adults with even older age than ours appear to benefit from exercise training by getting improved sleep quality and efficiency (objectively measured) even at lower intensity and shorter duration.^{17,31–33} Thus, the health status and age also play a role in the effects of exercise on sleep quality.

The mechanisms by which exercise improves sleep quality are likely multi-factorial. It has been suggested that the effects

of exercise on sleep are related to antidepressant effects, anxiety reduction, and changes in serotonin levels.^{20,34}

The strength of this study was that it was designed to compare exercise bouts at two different intensities but with the same volume. The energy intake in the morning was equal before both exercise bouts. This design was unique especially with regard to the energy conservation theory of sleep because we were able to tease out the effect of energy expenditure of exercise *per se* on sleep. Also, sleep was monitored in the home environment, and less susceptible to confounding of laboratory recording.

Although using actigraphy to estimate sleep is not as accurate as polysomnography, it has a number of advantages, including that it offers a convenient method for estimating sleep on multiple nights with limited burden to subjects, with acceptable reliability.^{35,36} Also, our participants did not use a diary to record the time they went to bed. Thus, we could only rely on the actigraphic recording to determine their time-in-bed, and was not able to accurately determine the time getting into bed. As a result, we decided not to report sleep latency (time from getting into bed to the point of falling asleep), but rather focus on wake time after sleep onset and activity counts during time-in-bed. Participants also did not record daytime napping. However, there did not appear to be markedly different periods of lack of activity of the actigraphic recording, in the afternoons on exercise days in comparison to baseline without exercise. In addition, the sample size of our study was small and inter-subject variance was large; nonetheless, our findings suggest an effect of exercise on sleep which warrants further investigation.

5. Conclusion

In this study, wake time after sleep onset, number of awakenings, and total activity counts were significantly reduced after a session of moderate-intensity aerobic exercise compared to those without exercise. Thus, we have demonstrated that an approximately 1-h single session of moderate-intensity brisk walking improves sleep quality in older women.

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